ACIDIC PRECIPITATION IN ONTARIO STUDY

(A.P.I.O.S.)

Summary of Research Results and List of Publications

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Historically, Environment Ontario and other North American environmental agencies have been dealing with contaminants as pollutants in their own right, concerned with their potential "localized" and "community" effects.

However, acidic precipitation studies to date have demonstrated that the precursors, SO_2, sulphates, and nitrates, are from sources which, in many cases, are distant from the sensitive receptor lakes. The severity of this problem of long range transport of air pollutants into Ontario became apparent to Ontario scientists when they began to analyze the results from several special studies, in particular, the Sudbury Environmental and Lakeshore Capacity Studies. Both of these geographically intensive programs measured atmospheric pollutants and quantified the proportion which, as a consequence of various physical and chemical means, ultimately end up in sensitive terrestrial and aquatic ecosystems.

In particular, these studies indicated that, when using contemporary monitoring and analytical techniques, the secondary or evolutionary pollutants associated with primary emissions of particulates and SO_2 were being deposited in large measure by the rain falling over extensive portions of the province with adverse effects on Ontario's very sensitive environment.

In response to the seriousness of this situation and recognizing its similarity with the Scandinavian problem, the Ontario Government initiated a major long range transport of atmospheric pollutants or "acidic precipitation" program in 1979.

The overall mandate of the program is "to protect Ontario's environment from the detrimental effects of acid precipitation and other air pollutants subject to long-range transport".

Because of the extensive environmental effects associated with the acid rain problem, Ontario's A.P.I.O.S. research program involves the participation of several provincial Ministries, with the Ministry of the Environment in the lead role. The Ministry of Natural Resources is cooperating extensively in the studies of fisheries and forestry effects.

The results of our scientific research to date include the following:

Atmospheric Processes Studies

- A sulphate wet deposition rate of 20 kg ha^{-1} yr^{-1} is currently exceeded in all of central and southern Ontario. The observed deposition pattern, with high values in the southern portion of the province, when merged with other Eastern North American data, suggests that the responsible emission source area is the northeastern U.S.A.

- On a province-wide basis, the annual dry deposition rate of sulphur is approximately one-quarter of the wet deposition rate, although in the southernmost portions of the province, the importance of sulphur dry deposition is greater (being about 50% of the wet deposition). Again, the air concentration and dry deposition pattern indicate a source area to the south of Ontario.

- The contribution of nitrates to acid loadings in the province is comparable to that of sulphates.

- The largest source area in the province - the nickel smelters at Sudbury - contributes a relatively small portion of the total atmospheric deposition of acidity and sulphates. Thus, control of the Sudbury smelters alone will result in only slight decreases in deposition at receptors in Ontario. Meteorological analysis indicates, for example, that the Sudbury contribution is about 15% or less of the total for wet deposition and 40% or less for dry deposition of sulphur oxides in Ontario.

- Much of the atmospheric deposition of acidifying substances is due to sources to the south of the province. The highest sulphate wet deposition at receptors in southern Ontario near the Canada-U.S. border (more than one-half the total), for example, is associated with air parcels coming from the direction of high emission density areas in Indiana, Ohio and Pennsylvania. At these receptors, sulphate wet deposition attributable to Ontario sources is 14% or less.

- Statistical and trajectory mathematical models describing long-range transport and acidic deposition have been completed and peer-reviewed and extensively applied in control strategy studies by the Ministry of the Environment. The models indicate that contribution of U.S. sources to wet sulphur deposition at Muskoka and southern Québec are 50% and 30% respectively.

- Model results indicate that reducing SO_2 from Canadian sources alone will not enable us to meet the target of 20 kg/ha·yr of wet sulphate deposition at all sensitive

receptors in Canada. U.S. SO_2 sources also need to be controlled if this target is to be met at all sensitive receptors in Canada.

Aquatic Effects Studies

- In central Ontario, acidic deposition derived from anthropogenic SO_2 emissions is the primary causal factor in recent lake acidification and a reduction in the anthropogenic emissions affecting this area will result in a decrease in lake acidity.

- Although there are few acidic lakes (i.e. alkalinity < 0) outside of the Sudbury region, there are a great number of very sensitive lakes and streams throughout the Precambrian part of southern Ontario.

- Short-term acidification (that is, the reversible loss of alkalinity resulting from episodes or events such as snowmelt or storms) is a commonplace occurrence in the Precambrian part of southern Ontario. After natural dilution is accounted for, sulphuric acid is usually the major cause of short-term acidification, although nitric acid is, in a few isolated cases, more important. Springtime pH depressions associated with snowmelt effects are very widespread in Ontario.

- Long-term acidification (that is, the gradual decline in alkalinity measured on an annual basis) is occurring very slowly with little or no measurable change observed in lakes and streams studied over five to nine years. The time-scale for acidification can probably be measured in decades.

- Sulphate has become the dominant anion in almost all waters in Precambrian southern Ontario.

- Reductions in lake acidity follow reductions in SO_2 emissions within a short time frame.

- Organic acids contribute to the acidity of some lakes and streams but do not contribute significantly to short-term acidification and are not, in general, a major factor in the acidification process.

- In addition to strong acids, substantial amounts of trace metals are supplied to lakes and catchments via long-range atmospheric transport. Lead, cadmium and zinc are of particular concern, with most lead of anthropogenic origin (fuel combustion) averaging about 700 kg km^{-2} over southern Ontario. Total lead fluxes are 100 to 500 times greater than natural fluxes.

- In a survey of approximately 4,500 Ontario lakes, it was found that 4.2% were acidified (alkalinity $< 0\ \mu eqL^{-1}$) and a

further 16.7% were extremely sensitive to acidic deposition (alkalinity > 0 μeqL^{-1} and < 40 μeqL^{-1}).

- The effects of acidification on aquatic biota are primarily a result of the toxic effects of hydrogen ion and inorganic monomeric aluminum.

- Early life stages of several amphibians are affected by H^+/Al concentrations that are observed in many lakes, streams and ponds.

- There are no apparent effects of acidification on either the zooplankton or macrophyte populations of lakes other than those in the Sudbury area. Some benthic stream invertebrates (mayflies, chironomids) are affected by observed H^+/Al levels, while others (caddisflies, blackflies) are not.

- Phytoplankton community structure is very different in acidic lakes (i.e. a much higher proportion of dinoflagellates which are not likely very food-chain functional). Phytoplankton biomass is not altered directly by acidification but may be indirectly affected by nutrient availability.

- Among phytoplankton species showing different pH and alkalinity tolerances are many species of diatoms and scaled chrysophytes whose identifiable remains are "preserved" in lake sediment. These methods are being worked out with application to a large calibration lake set (55 lakes). Application to cores from selected lakes is planned to determine rate of change of lakewater acidity.

- The odour producing species Chrysochromulina breviturrita has been shown in field and laboratory studies to grow well over a pH range of 4.5 to 6.9. This species has also been shown to have an unusually high selenium requirement. The hypothesis is that blooms will occur in low pH lakes receiving adequate supplies of selenium and sulphate (Se and S are chemical analogues).

- Some species of filamentous algae forming large masses in shoreline areas of lakes have been shown in laboratory and field studies to grow best at low pH. Although data are still preliminary, growth appears to be enhanced by acidification and reversed by neutralization.

- The sensitivity of the major species of fish in southern Ontario waters to strong acid and aluminum follows the sequence: common shiner > white sucker > walleye > lake whitefish > lake trout > smallmouth bass > brook trout. The first five of these species are affected in the laboratory at concentrations that are observed in lakes and streams.

- In Ontario, both habitat and fish communities have been lost near point source emissions such as Sudbury and Wawa.

- Recent improvements in water chemistry coincident with the reduction of emissions from Sudbury area smelters and the resumption of recruitment by some fishes indicate that habitat losses can be reversed if emissions are reduced.

- In a survey of approximately 55% of Ontario's 2,218 lake trout lakes, it was found that 6% were acidified (alkalinity $< 0\ \mu eqL^{-1}$) and 6.3% had pH levels < 5.5, a level of pH below which lake trout populations do not recruit successfully.

- Fish species richness (as species number) was found to decline with decreasing pH from pH 6.3. Thirty and one half percent of all lakes sampled have pH < 6.3 and hence may be limited in species richness by acidity.

- Ground waters from some domestic wells completed in sands and gravel are acidic. This acidity is caused by dissolved CO_2 and not by acidic precipitation.

- The residence time and flow path of water in the ground influence the acidity of the water. In the calibrated watersheds, deep ground waters that have passed through the deeper geologic zones are buffered better than shallow ground waters.

- Application of limestone or limestone slurry is an effective and cost efficient method of neutralizing lakes affected by acidic precipitation.

- Neutralization of two study lakes to alkalinities typical of many shield lakes did not cause adverse impacts on benthic or fish communities.

Terrestrial Effects Studies

- The results of simulated acid rain experiments with agricultural crops illustrate that plant response to simulated acid rain treatments is not only species dependent but also strongly cultivar dependent. Rainfall pH between 3.0 and 4.2 may have a negative effect, a positive effect or no effect on plant growth. Results have also indicated that plant response to simulated acid rain treatments is dependent on several factors:

  a) rain characteristics (treatment application rate and duration of event);
  b) disease and pests;
  c) environmental conditions (high temperature, drought); and
  d) interactive stress from air pollutants (ozone, sulphur dioxide and nitrogen oxides).

- The chemistry of lichen and moss tissue is influenced by regional pollution and contaminant sources as well as by long range transport associated with acidic deposition.

- There are elevated sulphur levels in lichen and moss tissue in southern Ontario. There is also a paucity of lichens in southern Ontario which can be ascribed to pollution and habitat disturbance.

- Naturally acidic soils (i.e. podzolic) are not as susceptible to changes in pH as less acidic soils such as brunisols.

- Acidic soils with a pH below 4.2 are subject to aluminum solubilization.

- Podzolic soils treated with acid rain simulants tend to adsorb added sulphate and nitrate becomes the mobile anion in leachates. Conversely, in natural forest soil systems, nitrate tends to be conserved in the soil and sulphate becomes mobile in drainage waters.

- Base cation content and carbonates are the most important chemical parameters when assessing soil sensitivity. Depth and texture are the most important physical parameters which determine the contact time between percolate and soil particles. Retention soil moisture within the soil matrix determines the degree to which chemical exchange between soil and water can occur.

- Throughfall is enriched in nutrient and trace elements as compared to incident precipitation. Enrichment of $SO_4^=$ under conifers is greater than under hardwoods under similar atmospheric deposition. Enrichment of $SO_4^=$ in throughfall is higher in areas of higher atmospheric deposition.

- Conifers, as a rule, induce a pH depression of throughfall water while hardwood species elevate the pH. These changes are on the order of a tenth of a pH unit.

- Shrubs contribute significantly more to the alteration of throughfall water, amplifying the role of the tree canopy in precipitation alteration.

- Stemflow is even more enriched in nutrient ions and trace elements. As with throughfall, the species of the tree bole has an influence on the degree of this enrichment. Stemflow differences between conifers and hardwoods are highly pronounced. Conifer boles can depress incident precipitation pH by one half to one full pH unit. Hardwood boles have the opposite effect.

- Nitrogen compounds tend to be conserved by the tree canopy and bole, the reverse trend of other nutrient ions.

- Soil leachate sampled at various horizons in a podzolic soil is more acidic (lower pH) than soil leachate from a brunisolic soil. Also, concentrations of $SO_4^=$ and Al in the podzolic soil leachate are higher.

- Sulphate concentrations in soil leachate are elevated following rain episodes which follow prolonged dry periods, possibly resulting from sulphur oxidation in the soil during the dry period.

- Nitrate in soil leachate is only detectable in the early spring or late fall, corresponding to tree dormancy periods. Therefore, nitrate is not an important mobile anion during the growing season.

- Despite weight losses due to decomposition of leaf litter, contents of N and K are elevated in decomposition litter bags. Presumably, such gain is due to microbial immobilization and/or adsorption at exchange sites.

- The current outbreak of sugar maple decline in the Muskoka area first became evident about 1978.

- Although some degree of decline was observed on maples in all age classes, it was most pronounced on older trees and trees which had been tapped for maple syrup production or otherwise wounded.

- Site nutrient deficiencies were not implicated in the decline of sugar maple.

- The soil at the Muskoka sugar maple sites was acidic and contained high amounts of soluble aluminum.

- Declining sugar maple trees in Muskoka suffered extensive root death and the fine roots had significantly higher aluminum concentrations than fine roots of healthy trees.

- A foliar chemical gradient was detected with reduced elemental concentrations in the tops of the tree crowns at Muskoka.

- Annual growth rings for both healthy and declining sugar maple trees were very narrow during two years of forest tent caterpillar defoliation.

- Subsequent to the collapse from the insect epidemic, growth recovered in the healthy trees but not in the declining trees.

- Incremental growth in the declining tree population appeared to be falling relative to the healthy trees for 20 years prior to caterpillar infestation.

- Early season droughts during the two years of insect defoliation (1976 and 1977) and again in 1983 and root infections by Armillaria mellea were some of the contributing factors to the tree decline.

- Acidic precipitation is considered to be an additional stress to the severe insect attacks and the spring droughts. Armillaria mellea root rot, tree age and site management are also contributing factors.

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